DISCUSSION OF PAPER BY W. H. KING, JR.: THE USE OF RESONATING DEVICES TO MAKE SMALL MASS MEASUREMENTS*

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DR. W. H. KING, JR., has described a system for obtaining measurements related to the mass of objects by incorporating these objects as part of the mechanical impedance in an oscillatory system where the vibrations are provided by a piezoelectric crystal. While the technique can be used validly under some circumstances to provide measurements of useful precision, it does not appear that the technique has great promise for the proposed application of measuring the weight of attached thrombus on a surface under a blood flow. The obstacles are essentially difficulties in interpretation of measurements obtained with such a device: the difficulties arise due to effects of damping and of the flexibility of thrombi. In the first place, the natural frequency of a harmonic oscillator having a known effective mass and spring force is dependent upon the relative magnitude of viscous damping; the effect of increasing the relative damping is to increase the period of oscillation. This effect is well known and can be allowed for *if* the viscous damping is known sufficiently well. With this technique the estimate of total mass is obtained from a measurement of frequency, so any corrections associated with damping are important, especially where the damping force may change as a thrombus grows. Under the circumstances proposed for application of this technique it appears that the effective viscous damping might not be sufficiently well known to provide a sufficiently accurate correction. The second and more difficult problem which would arise in application of this technique is that a clot is not a rigid structure which will move uniformly in small, high-frequency oscillations such as those generated by a piezoelectric crystal or even

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by an oscillator of considerably lower natural frequency. A thrombus is rather gel-like, and has mechanical properties which thus far have not been well characterized. Thrombi may be dominated by platelets or by a fibrin maze with entrapped cells, or they may take all sorts of intermediate structures; they may be striated, and are rarely homogeneous. Even for a thrombus of fixed dimensions it appears that mechanical properties are a function of time, because various actions occur inside clots, e.g., viscous metamorphosis. The problem of finding an adequate formulation for the constitutive relation of such materials—the relation between the stress tensor and the strain and rate of strain tensors—has not yet been resolved satisfactorily, especially with respect to mechanical properties found under high-frequency oscillation where the interaction of the mechanical properties and various internal relaxation times becomes very important. As a consequence it would not be possible at this time to predict the apparent mass which a thrombus would exert on the surface of a wall undergoing oscillations (in the manner suggested by Dr. King) in terms of the geometry of the thrombus and its mass, as would be seen by direct observation, and vice versa. Thus readings would be obtained that would have no direct interpretation in terms of thrombus size without extensive calibration relating the instrument reading to thrombus size, shape, morphology, and blood-flow rate, and there is a strong probability that particular values of the instrument reading would not be related uniquely to a specific thrombus size but rather to a whole range of sizes and structures which in combination give the same reading. There is also a strong possibility that the thrombus-formation process itself could be affected by the local wall oscillation which would be introduced by this technique.

Dr. King does have a very ingenious idea in presenting this device as a possible tool for measuring thrombus size, and despite the fact that there are serious (and at present insurmountable) problems in adapting his device to this use, we should not lose sight of the fact that the basic idea of relating the response of the surface on which a thrombus is growing to some sort of oscillation does provide a technique for assessment of an attached mass. However, it might be more fruitful at this stage in the development of the understanding of the behavior of material to employ oscillations of a different physical nature from those proposed by Mr. King. Thus we might consider the use of thermal oscillations, in which a fluctuating heat flux is applied very close below the surface of a test material, with magnitudes of temperature fluctuations insufficient themselves to cause significant blood damage. Thermocouple and semiconductor thin films exist which have very rapid frequency responses and which could detect a change in transfer of fluctuating heat input to the blood stream which could be caused by an attached layer of thrombus, and could provide a measure of its thickness within a certain range. The reason that this technique might work more satisfactorily is that the technique is basically insensitive to thrombus structure and would respond mainly to thrombus size. It may also be possible to obtain more localized information with this technique.